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THESIS

NPSAT1 MISSILE SYSTEM PRELAUNCH SAFETY PACKAGE (MSPSP)

by

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June 2004

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13. ABSTRACT (maximum 200 words)

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The scope of this thesis is to assess the safety risks associated with NPSAT1 for all activities occurring at the launch site through orbit insertion. This includes ground testing at the integration site, as well as in-flight operations prior to and shortly after separation from the launch vehicle. All hazards associated with NPSAT1 are to be enumerated and assessed for criticality. Hazard mitigation is to be presented preferably through subsystem design, but may also be performed through operations.

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NPSAT1 MISSILE SYSTEM PRELAUNCH SAFETY PACKAGE

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I. INTRODUCTION

A. PURPOSE

The purpose of this Missile System Prelaunch Safety Package (MSPSP) is to provide the Atlas V program a comprehensive safety assessment of the NPSAT1 payload subsystems that pose hazards to the launch vehicle and ground support personnel. This MSPSP is intended to enumerate all hazards associated with the NPSAT1 payload and provide sufficient information to show that NPSAT1 complies with the requirements specified in EWR 127-1 Range Safety Requirements.

B. SCOPE

This MSPSP provides a detailed description of hazardous and safety critical flight equipment, systems, and materials and their interfaces used in the Atlas V launch vehicle. The ground support equipment and integration testing section includes all activities associated with integration testing verification of NPSAT1 hardware and support equipment from arrival at launch site through launch.

This report identifies safety hazards that could result in major equipment damage and/or serious personnel injury. It presents an assessment of the risk of the current design resulting in equipment failure and human error. It evaluates the adequacy of designed hazard mitigation features and provides recommendations to minimize the risk from the perceived hazards.

If no hazard exists in a typical subsystem or discipline common to spacecraft, it is stated so in the text. This is done for completeness and to specifically address the typical hazards outlined in the EWR 127-1 requirement document.

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II. PAYLOAD DESCRIPTION

NPSAT1 is a 81.6 kg [180 lb] satellite manifested on the Department of Defense (DOD) Space Test Program (STP) Atlas V mission due to launch in September 2006. NPSAT1 is one of five secondary payloads to share the Atlas V using the evolved expendable launch vehicle (EELV) secondary payload adapter (ESPA). The overall configuration is shown in Figure 1, with the top, side, bottom, and isometric views shown. Figure 2 shows an expanded assembly drawing of the spacecraft depicting modules located within the spacecraft. The spacecraft is a 12-sided cylinder with body-mounted solar cells on all of the cylinder sides. Both ends of the cylinder have antennas mounted on them to allow for communications in the event the attitude of the spacecraft is not correctly nadir-pointing. This configuration assumes the risk, though remote, of an ACS failure combined with an attitude such that the cylinder longitudinal axis points at the sun in either the plus or minus sense for an extended period of time resulting in loss of solar panel illumination. Two deployable booms are shown; they are the CERTO beacon antenna and Langmuir probe boom, respectively.

The spacecraft subsystems include the command and data handling (C&DH) subsystem, electrical power subsystem (EPS), attitude control subsystem (ACS), radio frequency subsystem (RFS), and mechanical subsystems, which include the spacecraft structure, mechanisms, and thermal design. As a low-cost satellite, few space-rated components will be used, and the system will be a ‘single-string’ design. The spacecraft’s circular orbit with altitude of 560 km and 35.4^{o} inclination suggests a relatively radiation benign environment. Total dose for the spacecraft electronics is estimated at 200 rad (Si) per year*, however, radiation tolerant devices will be used for critical areas, such as in the EPS micro-controller and memory, to mitigate the risk of single event effects (SEE). Within the EPS micro-controller, a watchdog timer will be used as a check that the C&DH processor is operating properly. Should the

* Due to trapped protons and assuming 300 mil aluminum shielding

C&DH not reset the watchdog timer within a set time period, the EPS will cycle power to the C&DH forcing a reboot. Another design feature to be employed to mitigate SEEs is error-detection-and-correction (EDAC) memory in the C&DH.

The spacecraft is intended to operate with a great deal of autonomy. Except for the RFS, each of the spacecraft bus electronics subsystems (C&DH, ACS, and EPS) has its own processor. The EPS and ACS, as well as the Solar Cell Measurement System (SMS) experiment controller, are very similar in design taking advantage of design modularity. The C&DH performs the bulk of the scheduling of spacecraft and experiment operations. Because of limited available power, all experiments are required to be able to power off in order to save on electrical power. The C&DH is itself capable of undergoing a ‘deep sleep’ mode to save power, essentially halting its instruction clock. Focusing on good power management ensures the maximum return of science from the experiments. [Ref. 1, pg. 4]

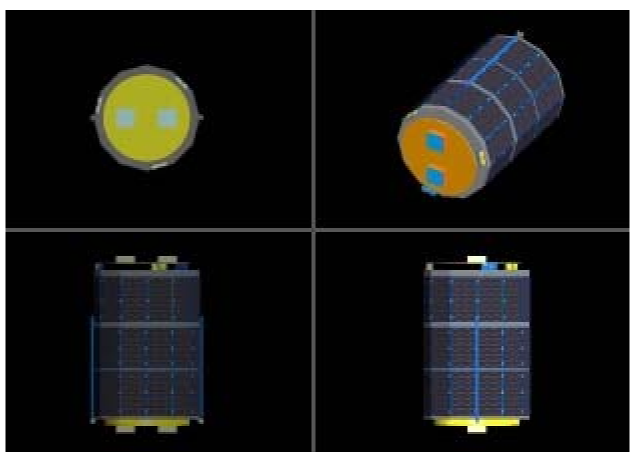

Figure 1: NPSAT1 Spacecraft Configuration. (From: Ref 1)

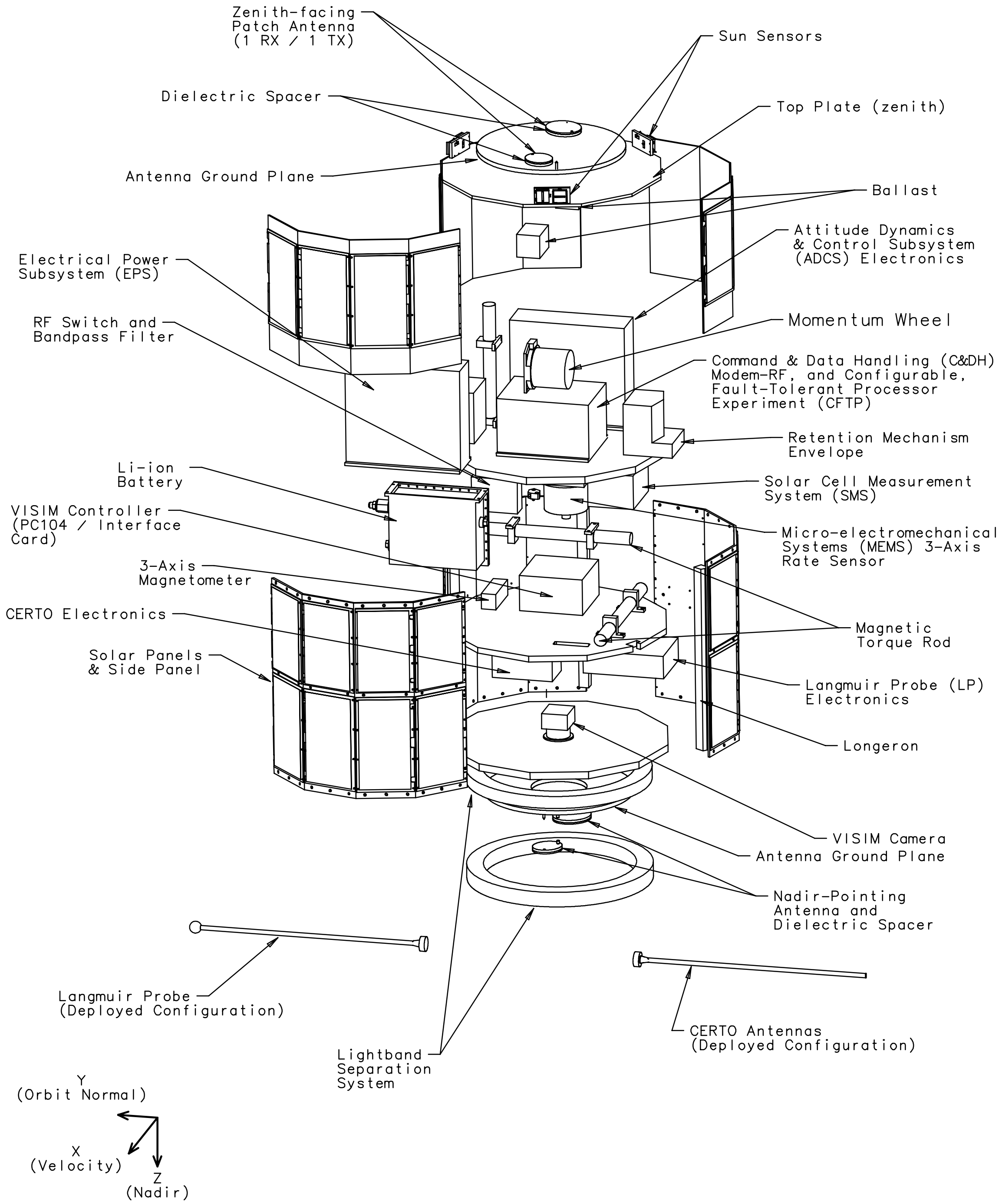

Figure 2: NPSAT1 Expanded View. (From: Ref 1)

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III. FLIGHT HARDWARE SUBSYSTEMS

A. LAUNCH VEHICLE INTERFACE

NPSAT1 is designed to be powered off while attached to the launch carrier. NPSAT1 has several inhibits to satisfy EWR requirements. The first is a no power bus concept that means NPSAT1 has a cold start on deployment. This feature basically prevents the batteries to charge or come on-line until the spacecraft is completely separated from the launch vehicle. See section V.F.1 for charging on the pad. There are two sets of parallel launch switches (S1-S4 on Figures 5 and 6) that interrupt the flow of power from the solar panels to the EPS until separation from the ESPA. The K2 relay (battery relay) is switched off just prior to removing the umbilical cord from the satellite during ground operations and check out. Once the EPS receives power, it will toggle the K2 battery relay to attach the battery to the main bus. This must be accomplished during the sunlit portion of the orbit and will not occur until the launch switches detect separation from the ESPA. The second inhibit is the K1 or CERTO relay which prevents inadvertent RF emissions and unscheduled deployments of the Langmuir probe and CERTO antenna. The K1 relay requires the second set of parallel launch switches to be closed to complete the control circuit from the C&DH. Figures 5 and 6 are the schematics of the launch interface that shows the main safety inhibits for NPSAT1 in the launch configuration (open circuits). After separation, all switches will close or toggle to the opposite position. Table 1 summarizes Figures 3 and 4.

Interface component	Function
Launch switch S1 & S2	Interrupts power flow from solar panels to EPS
Launch switch S3 & S4	Completes control circuit from C&DH to K1 relay
K1 Relay	CERTO Relay – interrupts power to deployment circuits and transmitters
K2 Relay	Battery Relay – interrupts power to batteries from EPS

Table 1: Interface Components

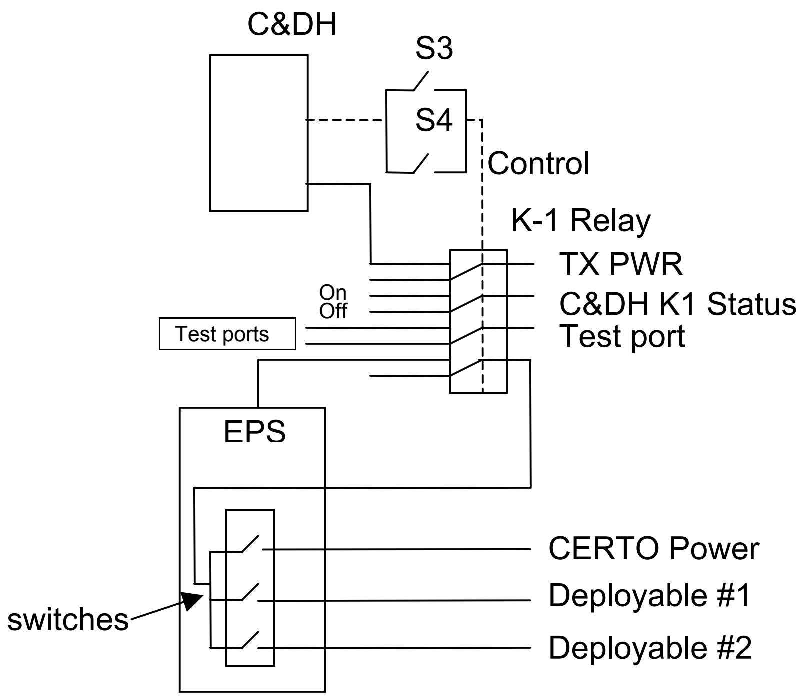

Figure 3: K1 Relay (Launch Configuration)

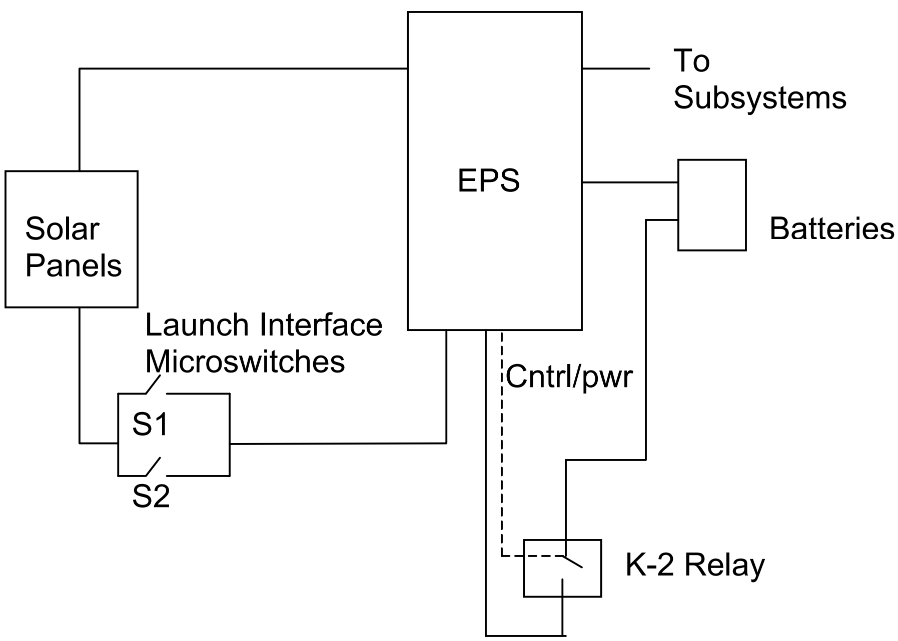

Figure 4: K2 Relay (Launch Configuration)

B. STRUCTURES AND MECHANISMS

The mechanical structure is based on heritage equipment from a canceled Navy, small satellite program; and is made entirely of aluminum. The load-bearing structure is very robust and consists mainly of a twelve-sided cylinder and three equipment plates. As a secondary payload, a robust structure was mandatory since the launch carrier was not known at the time of initial design. Furthermore, launch opportunities for secondary payloads are not guaranteed if the primary payload is canceled, grows beyond its initial margin, or is delayed due to funding or technical problems. Following manifesting on the STP-1 mission, no attempt was made to optimize the NPSAT1 structure for weight savings. Although the design limit loads for the STP-1 secondary payloads were not defined, a conservative estimate of 12 g static loads were applied with a factor of safety of 1.25 in all directions in a finite element analysis (FEA), i.e., 15 g in X, Y, and Z. The FEA results were combined by simply adding the results for each axis, X, Y, and Z, and provided margins of safety greater than 5.

An upper section was added to the load-bearing structure to accommodate additional solar panels, and is also used to mount an end plate, the zenith-pointing antennas, and the sun sensor modules required by the SMS. This upper section also allows for approximately two inches of area about the cylinder sides for the retention device for the deployable booms, and for handling points.

NPSAT1 mechanisms include the microswitches that are components included with the separation system as previously discussed in paragraph A of this section, the deployment mechanism of the deployable booms, and the retention mechanism that holds the booms in the stowed position.

The deployment mechanism of the CERTO antenna and Langmuir probe boom are heritage components. CERTO, and its deployment mechanism, have flown recently on the P91-1 ARGOS satellite and will launch aboard the C/NOFS satellite. The deployment mechanism is composed of a hinge at the base for rotation to the stowed position. The hinge is attached to a short stanchion, which is free to slide inside the base of the boom. The stanchion is connected to the

boom via a spring which, when the boom is released, pulls the boom and joins it with the hinged base via a conical mate, which aligns it normal to the base. The booms will deploy with alignment along the +Y axis and -Y axis of the spacecraft coordinate system, pointing in the plus and minus orbit normal directions.

Thermal analyses were performed on the NPSAT1 spacecraft; see Ref 6 for detailed analysis. Results of a thermal analysis showed that the solar cell temperatures, which are on the spacecraft exterior, range from -25°C to +29°C. This temperature range is sufficient for the industrial-grade electronics components used in NPSAT1. The operating temperature range of all decks in NPSAT1 for all subsystems ranged between -14°C and 16°C [Ref 6, Figures 35, 36, 38, 39, 42, 43, 46, and 47], which are within the survival temperature ranges [Ref 6, pg. 30]. The critical components for the thermal design are the batteries. The lithium-ion batteries allowable temperature range depends on whether they are in storage mode or operating. The storage mode range is -20°C and +45°C, the charge range is 0°C and +45°C and the discharge range is -20°C and +60°C. The battery design for the lithium-ion batteries accommodates a heater strip, and thermal isolation is planned for the batteries to lower the contact conductance between the battery box and the equipment plate. [Ref. 1, pg. 10]

C. PRESSURE, PROPELLANT AND PROPULSION SYSTEMS

NPSAT1 has no Pressure, Propellant or Propulsion systems.

D. ELECTRICAL AND ELECTRICAL SUBSYSTEMS

The electrical power subsystem (EPS) consists of triple junction solar cells for energy conversion, a lithium-ion (Li-ion) battery for energy storage, and the EPS control electronics which is composed of a processor board with all the digital logic and an analog/switching board for power switching and telemetry gathering. The solar cells are from Spectrolab and are part of a flight demonstration, which includes the solar cell measurement system (SMS) experiment. The minimum efficiency of these solar cells is 24%. The decision was made early in the program to use body-mounted solar arrays, (rather than deployable arrays), to reduce the risk of both inadvertent deployment and failure to deploy or partially deploy. Each cylinder side is used for solar cells. The

zenith-facing plate is not used because of the antenna and its respective ground plane. Power budget calculations were performed using a nominal nadir-pointing attitude with a beta angle (angle between the orbit plane and the sun vector) of 0^{o}. For the 35.4^{o} inclination orbit, the beta angle is between $\pm 20^{o}$ roughly 60% of the time, with a maximum at about 60^{o}. In order to save on power, all experiments are duty cycled and powered off when not in operation. The power budget uses average energy available per orbit rather than instantaneous power to arrive at scenarios of experiment operation. [Ref. 1, pg. 7]

The EPS electronics are built around a rad-hard UTMC80C196KD micro-controller on the digital board. The digital board also hosts a real-time clock, rad-hard RAM, the watchdog timer for the C&DH, a serial port to interface with the C&DH, and 8 kilobytes of ferroelectric (FERRO) RAM memory. The analog/switching board hosts all the power distribution to the other subsystems to provide a spacecraft power bus of 24V to 40V. Each subsystem is responsible for regulating the power from the bus for its own specific requirements. The analog/switching board is also responsible for taking measurements of such things as battery voltages and temperatures via 32 analog channels, which are multiplexed to a dual, 12-bit analog-to-digital (A/D) converter. [Ref. 8, pg. 8]

E. ORDNANCE SUBSYSTEMS

NPSAT1 has no Ordnance systems.

F. NON-IONIZING RADIATION SOURCES

The NPSAT1 radio frequency subsystem (RFS) is a full duplex system with 100 kilobits per second transmission rate on both the uplink and downlink channels. As stated earlier, the antenna system will be able to view in either the nadir-pointing direction or the zenith-pointing direction of the spacecraft in the event the spacecraft loses pointing capability. Only the nadir-pointing antennas will be used for communications in the nominal case where the spacecraft is properly nadir pointing. It is intended to build the frequency conversion electronics between the intermediate frequency (IF) and the transmit/receive frequencies in-house. [Ref. 1, pg. 8-9]

NPSAT1 will operate at 1767.565 MHz in the forward, or uplink channel, with a return link at 2207.3 MHz. The RFS uses a single-conversion to baseband with 70 MHz as the IF. A maximum bit-error-rate of $1x10^{-5}$ was set as a requirement for the system. The link budget shows positive margins of 13.6 dB for the forward link and 9.8 dB on the return link. The modem is physically located in the same housing as the C&DH. This is done because of the intimate connection between the modem and processor board. NPS is designing and building the modem. The FM Exciter, responsible for converting the GMSK baseband signal to the IF 70 MHz signal, and the FM Detector, which converts from the IF receive signal to the analog baseband, are of NPS design. [Ref. 1, pg. 9]

Preliminary radio frequency (RF) radiation analysis has not been done yet with respect to the Atlas launch vehicle. An EMI/EMC working group within the ESPA community is carrying out on-going discussions. However, neither the satellite nor its RFS transponder and its antenna are powered while in the Atlas V launch vehicle. The hazard mitigation to RF radiation is controlled through the K1 relay, which interrupts primary power going to the RF and CERTO transmitters. This relay requires the second set of parallel launch switches (S3 & S4) to be closed to complete the control circuit from the C&DH. As long as NPSAT1 is attached to the ESPA ring, the launch switches S1 and S2 will keep the solar panels disconnected from the bus.

G. OPTICAL AND LASER SYSTEMS

NPSAT1 has no Optical and Laser systems.

H. IONIZING RADATIONS SOURCES

NPSAT1 has no ionizing radiation systems.

I. ACOUSTICAL SUBSYSTEMS

NPSAT1 has no acoustical systems.

J. HAZARDOUS MATERIALS

The only potential hazardous material associated with NPSAT1 is the lithium-ion battery. This battery is a dry cell, which eliminates the potential leakage condition and will be discussed in Section V, paragraph E of this report.

K. COMPUTING SYSTEMS

In the launch configuration, the batteries are off-line by means of the K2 relay. Upon separation from the ESPA, power is provided through the solar panel bus to the EPS. The EPS then closes the K2 relay to put the battery on-line and powers up the C&DH and VISIM experiment. Powering up the VISIM is intended to capture pictures of the launch vehicle and the other secondary payloads. The EPS then powers up the ACS where initial attitude acquisition is performed to null the rates. NPSAT1 then periodically listens for the NPS ground station using both the nadir-pointing and zenith-pointing antennas. Once NPS contacts the spacecraft, orbit ephemeris is uploaded, the real-time clock is synchronized, images from the VISIM are downloaded, and spacecraft telemetry is downloaded to determine initial spacecraft operations. At this time, the CERTO and Langmuir probe booms may be deployed by NPS command. With timely orbit ephemeris onboard, NPSAT1 can initiate normal-mode pointing in the ACS, where the CERTO and Langmuir probe booms are pointing in the plus and minus orbit normal, and the base of the spacecraft, where the camera and transmit/receive antennas are located, is nadir-pointing. On-orbit checkout of the NPSAT1 spacecraft bus is expected to take two weeks, after which experiment operations can begin.

The NPSAT1 command and data handling (C&DH) subsystem consists of several electronic boards, which are attached using the PC/104 bus and housed within one large box. These boards are the C&DH motherboard, mass storage, A/D conversion and general-purpose input and output (I/O), the configurable, fault tolerant processor experiment (CFTP), the power supply, the modem, and other radio frequency subsystem (RFS) components. [Ref. 1, pg. 5]

The C&DH motherboard design is based on a PC-compatible architecture. PC/104 is a compact implementation of the standard PC bus, the industry standard architecture (ISA) bus, which provides hardware and software compatibility to the standard PC. The NPSAT1 C&DH incorporates most of the PC/104 electrical signals with a board size greater than the typical 3.6" x 3.8". Except for the need to conserve power and for Error Detection and Correction

(EDAC) RAM, the NPSAT1 command and data handling (C&DH) subsystem could be implemented using a commercial off the shelf (COTS) based PC/104 computer.

The C&DH uses an ARM microprocessor running at 33 MHz. There are 3 Mbytes of ROM and 16 Mbytes of EDAC static RAM. Five asynchronous serial ports, one port from the ARM and four using a multi-port module, provide subsystem communication and a network port for testing and integration. A serial communications controller (SCC) provides two bidirectional channels of synchronous serial in which one channel is used as the interface to the spacecraft modem. A field programmable gate array (FPGA) implements the PC/104 bus and the EDAC controller. The EDAC is one-bit correctable and two-bit error detectable and based on the design used by PANSAT.

The mass storage device, two analog-to-digital converters (A/Ds), I/O logic to drive the CERTO and Langmuir probe are located on one board. This board is called the I/O – A/D – Mass Storage Board. All modem control has been located on the power supply board. This board contains the switching power supplies, power input filter, serial communications controller (SCC) and a field programmable gate array (FPGA) to control the modem and RF interfaces.

The C&DH power supply provides all of the power conditioning (3.3V, 5.0V, and 12.0V DC) for the electronics within the housing, including the RF components. The RFS components within the C&DH are isolated from the other electronics for improved electromagnetic compatibility (EMC). [Ref. 1, pg. 6]

Linux, a POSIX-compliant operating system, was chosen as the operating system for the C&DH for several reasons. First, it is open-source software, which is robust and highly configurable. In addition it provides a multitasking and Unix-like environment for software development with which the Space Systems Academic Group has extensive experience. The software development tools are plentiful, free (no cost), and powerful. [Ref. 1, pg. 6]

The C&DH ROM implements a simple BIOS to initialize the ARM microprocessor and peripheral hardware to a known state. The BIOS will then load a compressed version of the Linux kernel. The kernel itself handles

decompression and startup of the kernel. At the completion of the kernel startup the system will load application tasks, which are also compressed on the ROM. A release of the Linux 2.4 kernel will be used. Recent developments for the NPSAT1 C&DH kernel are using 2.4.14 and 2.4.19 with the preemptive kernel patch. [Ref. 1, pg. 6-7]

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IV. GROUND SUPPORT EQUIPMENT AND INTEGRATION TESTING

A. STRUCTURES AND MECHANISMS

The only structures in the Ground Support Equipment and Integration testing are the lifting fixture and the handling dolly. The lifting fixture will be steel with steel bolts. The fixture will hold the NPSAT1 satellite, which will not exceed 200 pounds. It will be load tested to 400 pounds. Figure 5 is a drawing of the fixture.

A stress analysis was conducted on the lifting fixture components to determine load limits. The three ¼" – 20 turnbuckles are COTS parts. They have a load limit of 500 pounds each [Ref. 9, pg. 931]. Each of the ¼" – 20 bolts that attach to the turnbuckles will see no more than 67 pounds of load (200lbs/3). Since the force applied is directly down towards the earth (gravity) the shear plane passes through the threaded portion of the bolts. In order to determine the tensile-stress area of the threads we use $A_s = (pi/4)*(d-0.9743/n)^2$ [Ref. 8, pg. 23.6] were d is the diameter of the bolt and n is the threads per inch. Using ¼" – 20 stainless steel (18-8) bolts, the $A_s = (pi/4)*(0.25-0.9743/20)^2 = 0.0318in^2$. Using a maximum load of 200 pounds, the tensile stress each bolt will see is $P_b = (200/3)*(FS/A_s)$. Where FS is the Factor of Safety, which we assume to be 2. So, $P_b = (200/3)*(2/0.0318) = 4192.8$ psi. This means that the bolt threads should be able to withstand 4193 psi to give a factor of safety of 2. Using MIL-HDBK-5H table 2.7.1.0(b), the yield strength for an annealed sheet or strip of AISI 301 stainless steel per MIL-S-5059 (lowest yield strength on table) is 30,000 psi, which is over 6 times what the bolts will actually see. [Ref 10, pg 2-217]

The lifting eye or u-bolt is another COTS part. It has 3/8"-16 thread and a rated load limit of 1090 pounds [Ref. 9, pg. 2607].

NASA GSFC built the NASA Getaway Special (GAS) canister-handling dolly, see Figure 6. The manufacturer of the dolly, Swales and Associates, Inc provided Technical Report #89-72 to NASA [Ref. 11], which provides a thorough

Structural analysis. NASA's report is numbered GAS-GSE01-010 [Ref. 11] and will be provided to the Integrating Contractor.

Table 2 lists all of the Ground Support Equipment and the Material Handling equipment. The hazard column is Y or N based on EWR127-1 Paragraph 3.6 guidelines and the definition on page 3-xi.

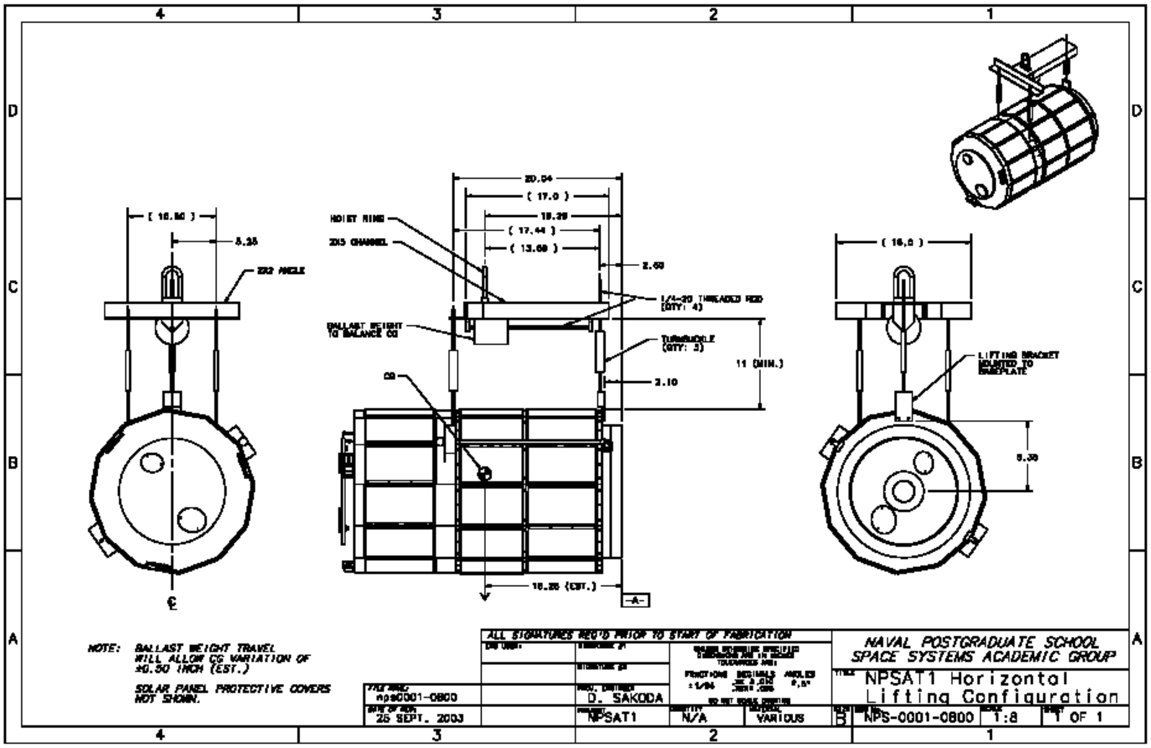

Figure 5: Lifting Fixture

Figure 6: Handling Dolly

Item	Desc.	Haz	Single Failure Point (SFP)	SFP Welds	Hazard Reports	Actual Load (lbs)	Load Tested (lbs)	Date Tested
Laptop		N				N/A	N/A	N/A
Power supply		N				N/A	N/A	N/A
Elect. Grnd. Sprt. Eqmt. breakout box		N				N/A	N/A	N/A
Hand tools		N				N/A	N/A	N/A
Power tools		N				N/A	N/A	N/A
Lightband force indicator		N				N/A	N/A	N/A
Handling/lifting fixture	See Figure 5	Y	Lifting eye	N	Stress analysis	180 lbs	400 lbs	
Handling dolly	NASA GAS canister handling dolly (fig. 6)	Y		N	GAS-GSE01-010	180 lbs	400 lbs	
EGSE cables		N				N/A	N/A	N/A

Table 2: Material Handling Equipment/Ground Support Equipment

B. INTEGRATION AND TESTING

NPS will be performing a specific set of activities to support NPSAT1 integration at the launch site. See Appendix C for the detailed description of these activities. To summarize these activities, NPS will first ship NPSAT1 and all GSE to Cape Canaveral Air Force Station (CCAFS). Upon arrival at CCAFS, NPSAT1 and the GSE will be unloaded, inspected and a post-ship functional test will occur in the processing bay. Then the spacecraft to ESPA mating will occur. At this point the ESPA harness verification and test will be performed. This will include a continuity check and cross-wiring check. The next step will be the verification of the launch vehicle umbilical between the service building and NPSAT1. Once connected, a functional test will be performed to verify proper SV operation. Then final battery charging will be performed and verification of separation switch positions and relay positions.

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V. SAFETY ASSESSMENT

The safety assessment of the NPSAT1 satellite identified several potential risks to equipment and/or personnel during pre-launch integration and testing and during the launch to orbit phase. Each will be addressed in the following sections.

The main safety feature of the NPSAT1 spacecraft is the “no power bus” condition as described in paragraph C of this section. (This feature basically prevents electrical power distribution of the spacecraft in the launch configuration.) Table 3 lists all the hazards that will be discussed in the following paragraphs.

Probability and severity are defined in EWR 127-1 Chapter 1 Table 1-1. The categories of severity are: I - catastrophic, which may cause death or over $1M in equipment loss; II - critical, which may cause severe injury or illness or equipment loss between $1M and $200K; III - marginal, which may cause minor injury or illness or equipment loss between $200K and $10K; and IV - negligible, which causes no injury or illness and less than $10K in equipment loss. The probabilities are defined as the likelihood that the event will occur. They are: A – frequent; B – reasonably probable; C – occasional; D – remote and E – extremely improbable. [Ref. 3 pg. 1-15]

Inhibit/Mitigation **Hazard**	S1, S2	S3, S4	K1	K2	S/W cmd		Analysis	Verification test	Procedure	Severity	Probability
Structural failure							X	X		I	E
Boom deployment		X	X		X			X		IV	E
Operation of EPS	X			X					X	III	E
RF radiation		X	X		X					IV	E
Battery leak/rupture							X	X	X	III	E
GSE											
Battery charging									X	III	D
Electrical shock							X		X	IV	D
RF radiation					X				X	IV	E
Lifting fixture							X	X	X	I	E
Dolly failure/tip							X	X	X	I	E
Sharp corners/edges/pinch pts									X	IV	D
Tool damage/injury									X	III	D

Table 3: Hazard Inhibits/Mitigations

A. STRUCTURAL FAILURE

As noted in Section III, paragraph B, a conservative estimate of 12 g static loads were applied with a factor of safety of 1.25 in all directions in a finite element analysis (FEA), i.e., 15 g in X, Y, and Z. The FEA results were combined by simply adding the results for each axis, X, Y, and Z, and provided margins of safety greater than 5. Structural failure is highly unlikely in normal launch conditions although actual design limit loads are not defined. Once environment levels are defined, qualification testing will be performed as part of the structural verification testing.

B. INADVERTENT BOOM DEPLOYMENT

NPSAT1 has two deployable booms approximately 0.5 meter (20 inches) in length and 1 centimeter (0.37 inch) in diameter. The booms are located on the spacecraft outer diameter, mounted below the base plate, which attaches to the separation system. The launch switches and the “K1” relay, which interrupt primary power going to the deployment circuits, and software command, mitigate inadvertent deployment of these booms. This relay requires the second set of parallel launch switches to be closed to complete the control circuit from the C&DH. The boom deployment is commanded from the ground and therefore cannot occur without power.

The retention mechanism is being designed and manufactured by the Naval Research Lab (NRL). It will be tested through random vibration and thermal cycle testing. The retention mechanism is controlled by the “K1” relay as mentioned above. The possibility exists that booms could deploy due to mechanical failure during launch. NRL will complete environmental testing to show that structural or mechanical failure is not a credible failure.

In the unlikely event of deployment, orientation of NPSAT1 booms is such that they will not contact anything.

C. INADVERTENT OPERATION OF EPS

NPSAT1 uses the “no power bus” concept that means it has a cold start on deployment. There are two parallel launch switches that interrupt the flow of power from the solar panels to the EPS. Once the EPS receives power, it will

toggle the “K2” battery relay to attach the battery to the main bus. This must be accomplished during the sunlit portion of orbit. As long as NPSAT1 is attached to the ESPA ring, the two launch switches S1 and S2 will keep the solar panels disconnected from the bus.

The battery relay switch (which is external to the battery) keeps the battery disconnected until the EPS sets the relay. The EPS will not power up until the solar panel launch switches close after separation from the launch vehicle.

D. RADIO FREQUENCY RADIATION

As discussed in Section III.F paragraph 3, Preliminary radio frequency (RF) radiation analysis has not been done with respect to the Atlas launch vehicle. However, neither the satellite nor its RFS transponder and its antenna are powered while in the Atlas V launch vehicle. As long as NPSAT1 is attached to the ESPA ring, the S1 and S2 launch switches will keep the solar panels disconnected from the bus.

E. BATTERY LEAKAGE/RUPTURE

NPSAT1 uses a new technology lithium-ion battery for internal power while on orbit. This battery is a dry cell rather than liquid, which eliminates a potential leakage condition. Since the battery cell is Underwriters Laboratories (UL) listed [Ref. 12], it is not subject to the testing requirements of section 3.14.4 (Lithium-Ion Battery Test Requirements) of the EWR127-1. This lithium-ion battery is expected to be significantly less hazardous than other lithium based or nickel based batteries.

This battery consists of 49 Sony US18605S cells in seven strings of seven cells. Each cell has an advertised standard rated capacity of 1.5Amp-hrs and a full charge voltage of 4.2V$\pm$ 0.5V. This cell has a hard carbon cathode with a nominal voltage of 3.6V. Estimated capacity of the assembled battery pack is 220 W-hrs at a cell de-rated capacity of 1.25A-hr. [Ref. 7, pg.1]

The battery assembly will be hermetically sealed and purged with dry nitrogen and will be leak tested. Electrical connectors are MIL-C-38999 Series I hermetic connectors. The battery housing is Al 6061-T6 and is a sealed

container (1 atmosphere of pressure) not a pressure vessel. The housing contains a pressure relief valve and microporus filter to maintain 1 atmosphere pressure.

F. GROUND SUPPORT EQUIPMENT

1. Battery Charging

Once the launch vehicle and its integrated payloads are on the launch pad the status of NPSAT1's battery can be monitored from the Equipment Service Building (ESB) where the Ground Support Equipment is located. Battery charging operations will also be performed from the ESB. While charging the battery the following telemetry points will be monitored continuously: total charge current, battery string charge current (7), battery voltage, and battery temperature. Battery charging will be controlled by the electrical power system on board NPSAT1, which will not allow the battery to be charged outside normal limits. As a backup, the GSE located in the ESB will monitor the telemetry stream and halt charging should any telemetry point exceed the normal charging limits. [Ref. 7, pg.1]

2. Electrical Shock

There is a slight possibility of personnel injury due to electrical shock. All measures to reduce this hazard will be followed including proper grounding, routing and insulation of all electrical equipment and wiring as well as the proper use of personal protective equipment. NPSAT1 will not produce more than 28 volts DC at 3 amps, which is much more than any subsystem will use. The harness consists of #20 single conductor, #20 twisted pair and #20 shielded pair.

3. RF Radiation

Any emitters of RF radiation during the processing phase will use antenna hats. There are no emitters on the final check on the pad.

4. Lifting Fixture or Dolly Failure

There is a slight risk that the NPSAT1 NASA GAS canister handling fixture (dolly) could fail or tip over while NPSAT1 is attached causing severe damage to NPSAT1 or serious injury to personnel. This risk is mitigated in that the handling fixture will be load tested to 400 pounds. A structural analysis provided by the

manufacturer of the dolly (paragraph IV.A) showed that it would be virtually impossible for a small weight of 180 pounds to tip the stand over.

There is also a slight risk that the lifting fixture could fail during lifting of NPSAT1. The lifting fixture will be load tested to 400 pounds and a stress analysis was conducted on the fixture (paragraph IV.A).

5. Sharp Corners/Edges, Pinch Points

The only sharp corners/edges and possible pinch points on NPSAT1 are the solar panels. All solar panels will be covered with protective covers to not only protect the solar panels but to eliminate the possibility of personnel contacting sharp corners or edges and possible pinch points. Self-captive fasteners will also be used to reduce sharp edges.

6. Hand/Power Tool Damage/Injury

Hand and power tools always pose a potential risk in causing damage to equipment or injury to personnel. Safety briefings will be conducted every morning prior to start of work during the integration process. All personnel will be instructed on the proper use of tools and the extremely sensitive nature of the work they are performing. All hand tools will be attached to personnel by a lanyard.

VI. CONCLUSION

NPSAT1 has safety features that satisfy EWR127-1 requirements and virtually eliminate hazards. One is the no power bus concept, which means a cold start on deployment. Another prevents inadvertent RF emissions and unscheduled boom deployments. In the unlikely event of boom deployment, NPSAT1 is placed in the launch vehicle in such a way that the booms would not touch anything and therefore not cause any damage.

Both electrical and mechanical Ground support equipment were assessed to ensure safety requirements are met.

Safety briefings will be conducted every morning prior to the start of work in the integration process to stress safe work habits.

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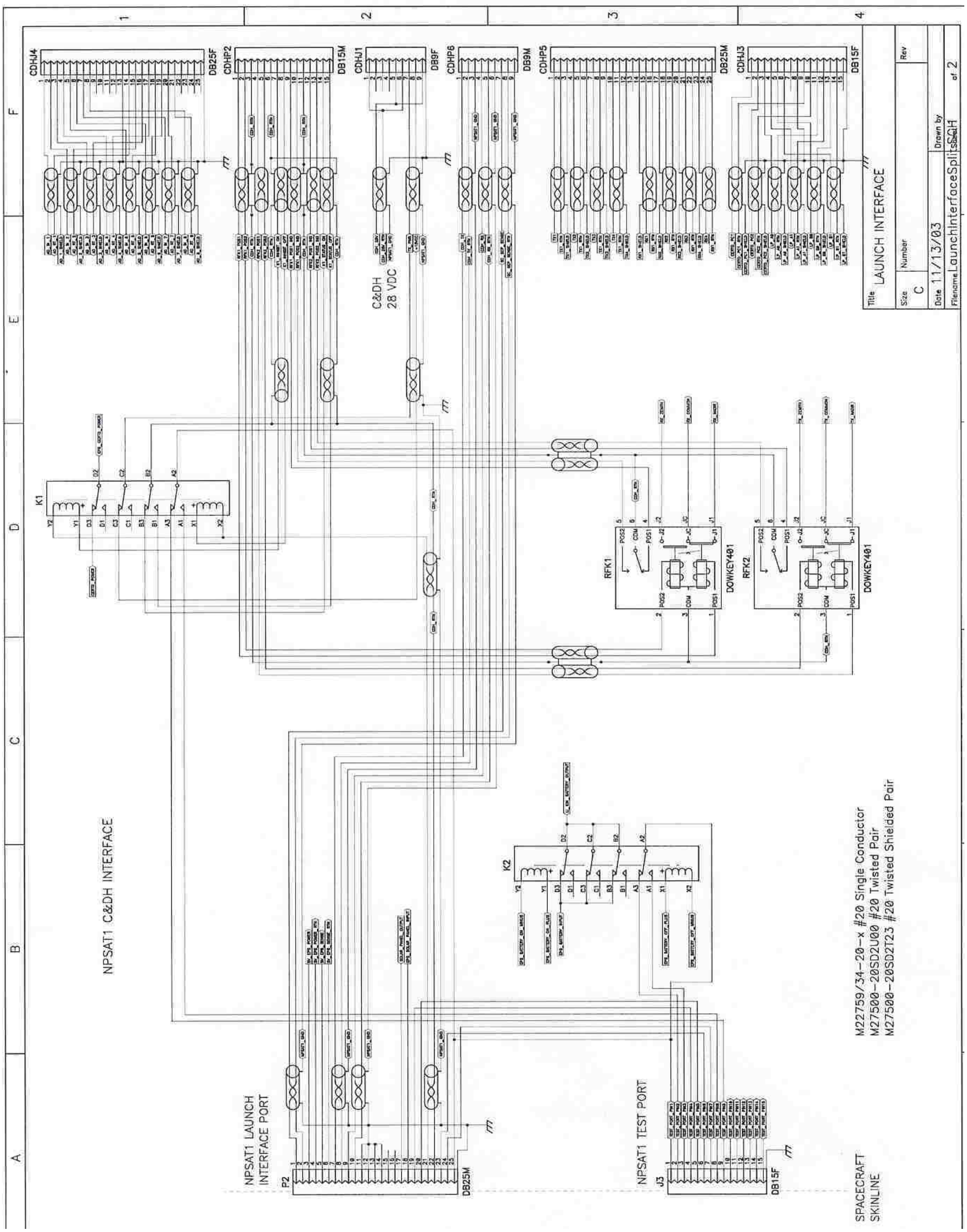
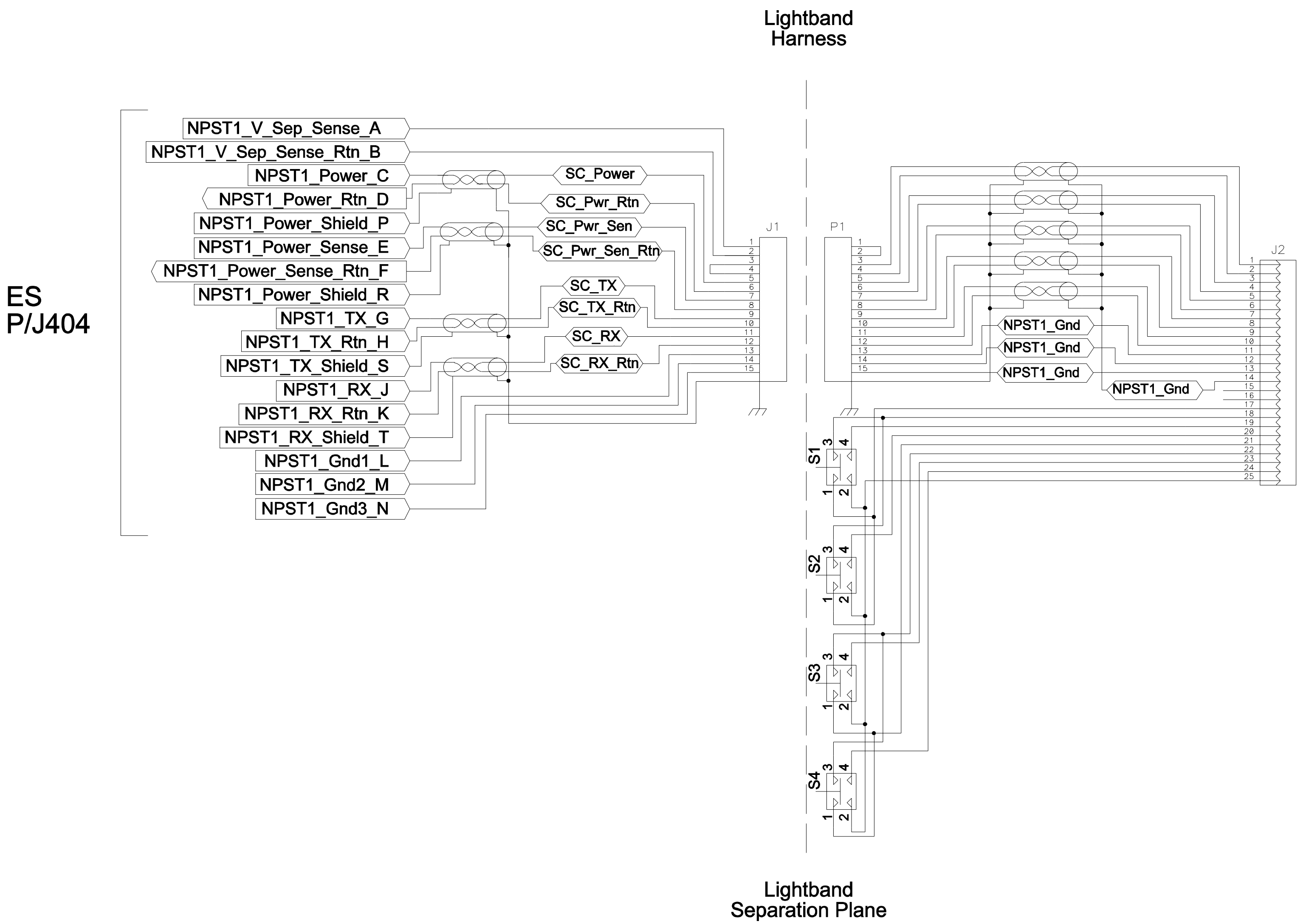
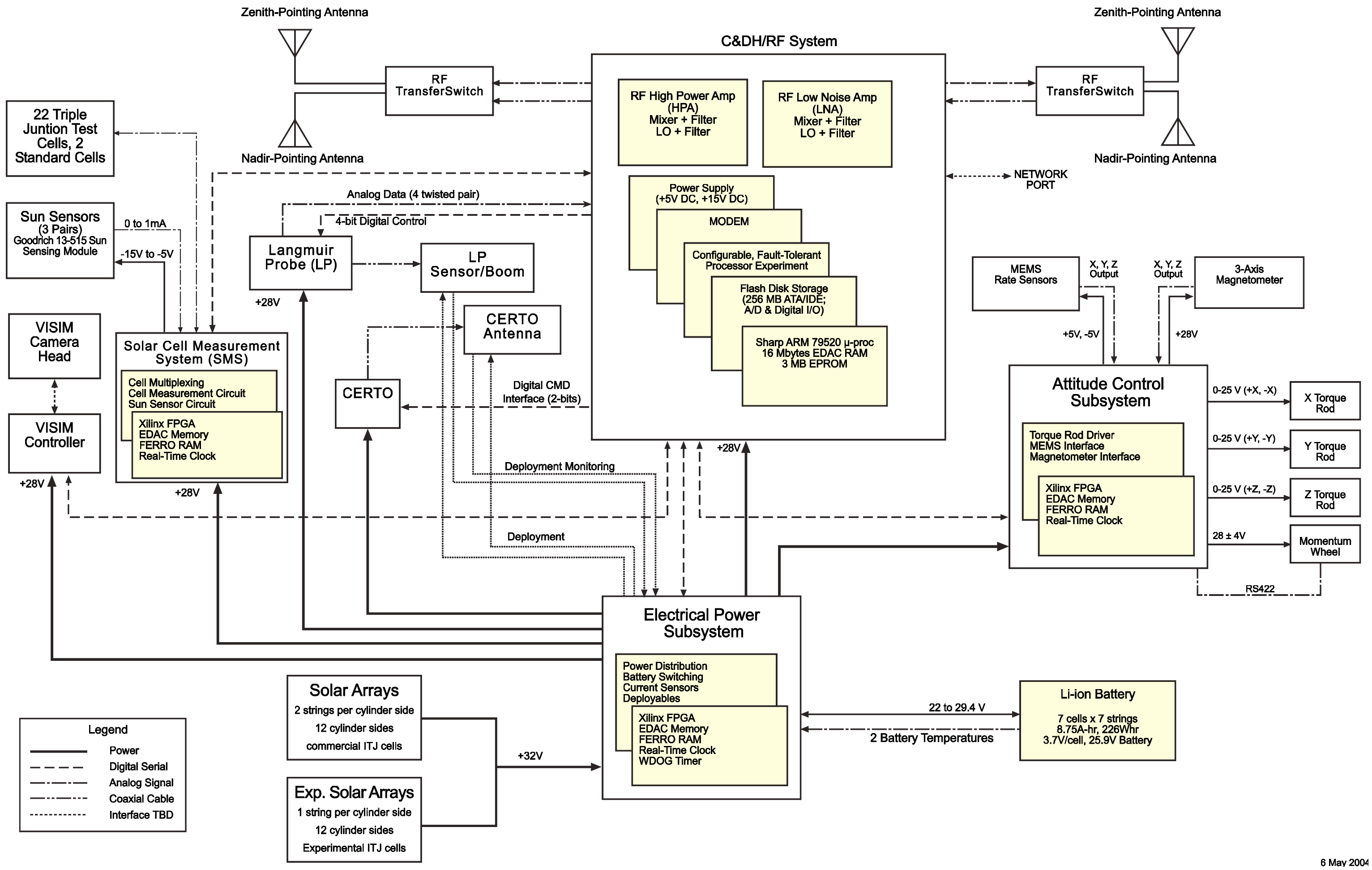
APPENDIX A- LAUNCH INTERFACE DIAGRAMS





Lightband
Harness
ES
P/J404
NPST1_V_Sep_Sense_A
NPST1_V_Sep_Sense_Rtn_B
NPST1_Power_C
NPST1_Power_Rtn_D
NPST1_Power_Shield_P
NPST1_Power_Sense_E
NPST1_Power_Sense_Rtn_F
NPST1_Power_Shield_R
NPST1_TX_G
NPST1_TX_Rtn_H
NPST1_TX_Shield_S
NPST1_RX_J
NPST1_RX_Rtn_K
NPST1_RX_Shield_T
NPST1_Gnd1_L
NPST1_Gnd2_M
NPST1_Gnd3_N
SC_Power
SC_Pwr_Rtn
SC_Pwr_Sen
SC_Pwr_Sen_Rtn
SC_TX
SC_TX_Rtn
SC_RX
SC_RX_Rtn
J1
P1
J2
NPST1_Gnd
NPST1_Gnd
NPST1_Gnd
NPST1_Gnd
S1
S2
S3
S4
Lightband
Separation Plane

APPENDIX B – BLOCK DIAGRAM



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APPENDIX C – INTEGRATION AND TESTING PROCEDURES

A. INTRODUCTION

NPS (Naval Postgraduate School) will be performing a specific set of activities to support NPSAT1 integration at the launch site. These include Space Vehicle (SV) post-ship testing, final checkout and closeout, ESPA mate, ESPA harness verification, Atlas V umbilical verification, battery charging and SV checkout on the pad from the equipment service building.

1. Detailed Sequence and Time Span

a. Ship SV and Ground Support Equipment

Duration of this activity is two workdays

NPS will ship the Space Vehicle (SV) and Ground Support Equipment (GSE) in separate containers. A suitable commercial shipping company will be used to transport the SV and GSE from NPS, Monterey California to CCAFS in Florida.

The SV and GSE will be delivered to the airlock / loading bay of the designated DSCS Processing Facility (DPF) at Cape Canaveral Air Force Station (CCAFS). Prior to unloading, all shipping containers will be visually inspected, and shock witness devices examined. Equipment will be unloaded from the truck using pallet jacks, range-supported forklift, or truck's lift gate.

The GSE will be moved to the designated Payload Control Center (PCC), unpacked and set up. GSE cables will be cleaned as necessary and run between the PCC and the designated processing bay. The SV and support equipment will be cleaned as necessary and moved into the processing bay. NPS will provide all hand tools required to support the SV processing. These tools will be compatible with the clean environment of the DPF.

Digital photographs of all major events are required for documentation purposes.

Range Support Needed:

Forklift and operator

Authorized photographer and equipment

Designated Payload Control Center in the DPF

Designated processing bay in the DPF

Cable access between the processing bay and the Payload Control Center

Storage space for shipping containers for the duration of processing activities at CCAFS

Office space or area with phone lines, Ethernet / network connections, copier facilities

Isopropyl alcohol for cleaning

Tra-Con Inc., Tra-Bond BIPAX BA-2116 for staking

ND Industries, Vibra-Tite formula 3 for locking threads

b. Post-ship Functional Test

Duration of this activity is two workdays

Once the SV is set up in the processing bay and all GSE connections are in place, a post-ship functional test will be performed. This test will represent a comprehensive performance check for proper SV operation.

Coax cabling will be used to perform a functional test of the telemetry transponder. A serial connection will be used to test the communication path through the launch interface.

Digital photographs of all major events are required for documentation purposes.

Note: There will be no emitters of Radio Frequency (RF) radiation during the processing of the SV.

Range Support Needed:

Authorized photographer and equipment

c. ESPA Mate

Duration of this activity is one workday

The mate of the SV to the ESPA ring will involve both NPS and Boeing IC procedures. NPS will position the SV horizontally using a GSE rollover

fixture and attach a horizontal lifting fixture to the SV. The IC is expected to operate the overhead gantry crane. The sequence of events will be as follows:

1. Roll SV to horizontal using an NPS supplied GSE rollover fixture
2. Install SV horizontal lifting hardware
3. Configure horizontal lift fixture and attach lifting slings
4. Position horizontal lift fixture over SV and attach lifting slings
5. While supporting SV with crane, remove Lightband bolts from rollover fixture
6. Lift SV into position for ESPA mate
7. At this point, responsibility is handed off to the Boeing IC to:
    a. Follow Boeing IC procedure for mechanically attaching Lightband to ESPA
    b. Follow Boeing IC procedure for electrically attaching Lightband to ESPA

Digital photographs of all major events are required for documentation purposes.

Range Support Needed:

Boeing IC procedures for mechanically attaching Lightband to ESPA

Boeing IC procedure for electrically attaching Lightband to ESPA

Boeing IC or Range provided Gantry Crane and operator

Authorized photographer and equipment

d. ESPA Harness Verification and Test

Duration of this activity is one workday

NPS would like to perform a final ESPA Harness Verification to confirm the pinout of the umbilical prior to mating of the ESPA with the launch vehicle. A continuity check combined with a cross-wiring check (to detect shorts) is sufficient. NPS will provide a break-out box that will connect to the launch interface connectors on the Lightband end of the SV. Appropriate break-out cables for the ESPA harness will need to be identified and used for this test.

Digital photographs of all major events are required for documentation purposes.

Range Support Needed:

Access to the ESPA Harness at the end which mates to the Delta IV launch vehicle.

Boeing IC support will be required while working with the ESPA harness.

Break-out cable for ESPA Harness

Authorized photographer and equipment

e. Verify Launch Vehicle Umbilical between Service Building and NPSAT1 SV

Duration of this activity is one workday

Once the ESPA ring is mated to the LV, NPS would like to perform a wire and pin verification on the LV umbilical before Electrical GSE is connected in the equipment service building. Once connected, a functional test will be performed to verify proper SV operation. Final battery charging will be performed; verification of separation switch positions and verification of safety inhibit relay and battery isolation relay positions.

Note: There will be no emitters of Radio Frequency (RF) radiation during SV final check out on the pad.

Digital photographs of all major events are required for documentation purposes.

Range Support Needed:

Pad access to the equipment service building.

Authorized photographer and equipment

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